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Title of the Invention:
OPTICAL INFORMATION RECORDING MEDIUM AND METHOD FOR MANUFACTURING THE SAME

I, Shin TANIMURA, whose full post office address is IKEUCHI·SATO & PARTNER PATENT ATTORNEYS, 26th Floor, OAP Tower 8-30, Tenmabashi, 1-Chome, Kita-ku, Osaka-shi, 530-6026, Japan am the translator of the document attached and I state that the following is a true translation to the best of my knowledge and belief of JP 2002-297291.

At Osaka, Japan
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Signature of the translator

Shin TANIMURA

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[Inventor]
[Address] c/o Matsushita Electric Industrial Co., Ltd., 1006-banchi, Oaza-kadoma, Kadoma-shi, Osaka-fu
[Name] Haruhiko HABUTA
[Inventor]
[Address] c/o Matsushita Electric Industrial Co., Ltd., 1006-banchi, Oaza-kadoma, Kadoma-shi, Osaka-fu
[Name] Kenichi NAGATA
[Inventor]
[Address] c/o Matsushita Electric Industrial Co., Ltd., 1006-banchi, Oaza-kadoma, Kadoma-shi, Osaka-fu
[Name] Yoshitaka SAKAUE
[Inventor]
[Address] c/o Matsushita Electric Industrial Co., Ltd., 1006-banchi, Oaza-kadoma, Kadoma-shi, Osaka-fu
[Name] Hideo KUSADA

[Patent Applicant]
[Identification Number] 000005821
[Name/Title] Matsushita Electric Industrial Co., Ltd.
[Attorney]
[Identification Number] 100097445
[Patent Attorney]
[Name] Fumio IWAHASHI
[Appointed Attorney]
[Identification Number] 100103355
[Patent Attorney]
[Name] Tomoyasu SAKAGUCHI
[Attorney]
[Identification Number] 100109667
[Patent Attorney]

[Name] Hiroki NAITO

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[DOCUMENT NAME] SPECIFICATION

[TITLE OF THE INVENTION] OPTICAL INFORMATION RECORDING MEDIUM AND METHOD FOR MANUFACTURING THE SAME

[CLAIMS]

[Claim 1] An optical information recording medium comprising a first information layer and a second information layer being separated from each other by an optical separating layer,

wherein the first information layer includes a low refractive index layer that is in contact with a recording layer and the optical separating layer, and

with respect to a laser beam having a wavelength of $\lambda_o$ used to record on or reproduce from the optical information recording medium, when a refractive index of the low refractive index layer is taken as n1, and a refractive index of the optical separating layer is taken as n4, n1 and n4 satisfy:

$$|n1-n4| \leq 0.5.$$

[Claim 2] The optical information recording medium according to claim 1,

wherein the first information layer includes at least the recording layer, a reflective layer, a transmittance adjusting layer, and the low refractive index layer in this order as viewed from a side into which the laser beam enters,

with respect to the laser beam, a transmittance of the first information layer when the recording layer is in the crystalline state is taken as Tc1 (%), and a transmittance of the first information layer when the recording layer is in the amorphous state is taken as Ta1 (%), Tc1 and Ta1 satisfy:

$$40 < Tc1 \text{ and } 40 < Ta1, \text{ and}$$

with respect to the laser beam having a wavelength of $\lambda_o$, when a refractive index of the reflective layer is taken as n3, an extinction coefficient thereof is taken as k3, a refractive index of the transmittance adjusting layer is taken as n2, and an extinction coefficient thereof is taken as k2, one of the following relationships is satisfied:

$$1.0 \leq (n2-n3) \leq 3.0 \text{ or}$$

$$1.0 \leq (k3-k2) \leq 4.0.$$

[Claim 3] The optical information recording medium according to claim 1

or 2,

wherein the low refractive index layer comprises at least one selected from the group consisting of $SiO_2$, $Al_2O_3$, $LaF_3$, $ZrSiO_4$, and $ZrO_2$.

[Claim 4] The optical information recording medium according to any one of claims 1 to 3,

wherein a film thickness d1 of the low refractive index layer is in a range of 1 nm to 25 nm.

[Claim 5] A method for manufacturing an optical information recording medium comprising a first information layer and a second information layer being separated from each other by an optical separating layer, the method comprising:

(a) forming the second information layer,

(b) forming the optical separating layer on the second information layer,

(c) forming the first information layer on the optical separating layer,

wherein when forming the first information layer on the optical separating layer, the low refractive index layer, the transmittance adjusting layer, and the reflective layer are formed in that order, and

when a refractive index of the low refractive index layer is taken as n1, a refractive index of the transmittance adjusting layer is taken as n2, an extinction coefficient thereof is taken as k2, and a refractive index of the reflective layer is taken as n3, an extinction coefficient thereof is taken as k3, and a refractive index of the optical separating layer is taken as n4, n1 to n4 and k2 and k3 satisfy:

$1.0 \leq (n2-n3) \leq 3.0$ or

$1.0 \leq (k3-k2) \leq 4.0$ and

$|n1-n4| \leq 0.5$.

[Claim 6] The method for manufacturing an optical information recording medium according to claim 5,

wherein the low refractive index layer comprises at least one selected from the group consisting of $SiO_2$, $Al_2O_3$, $LaF_3$, $ZrSiO_4$, and $ZrO_2$.

[Claim 7] The method for manufacturing an optical information recording medium according to claim 5 or 6,

wherein a film thickness d1 of the low refractive index layer is in

a range of 1 nm to 25 nm.

[DETAILED DESCRIPTION OF THE INVENTION]

[0001]

[Technical field to which the invention pertains]

The present invention relates to a multilayered optical information recording medium in which information is recorded, erased, rewritten and reproduced optically on a plurality of information layers by irradiation of laser beams or the like.

[0002]

[Prior art]

In a phase change information recording medium, information can be recorded, erased and rewritten by utilizing a recording layer in which phase change is caused reversibly between a crystalline phase and an amorphous phase. When the recording layer is irradiated with a laser beam at a high power and then cooled, the irradiated portion becomes an amorphous phase. Furthermore, when the amorphous portion of the recording layer is irradiated with a laser beam at a low power and then gradually cooled, the irradiated portion becomes a crystalline phase. Therefore, in the phase change optical information recording medium, the recording layer can be changed arbitrarily into the amorphous phase or the crystalline phase by irradiating the recording layer with a laser beam whose power is modulated between a high power level and a low power level. In the information recording medium, information is recorded by utilizing a difference between the reflectance in the amorphous phase and the reflectance in the crystalline phase.

[0003]

In recent years, in order to improve the recording density of the information recording medium, various techniques have been researched. For example, the following techniques have been researched: a technique by which a smaller recording mark is recorded by using a blue-violet laser beam; and a technique by which a smaller recording mark is recorded by reducing the thickness of a substrate provided on the light incident side and using a lens having a large numerical aperture. Moreover, there is a technique by which information is recorded and reproduced on two information layers by using a laser beam incident from one side (See Patent document 1, for example).

[0004]

In the optical information recording medium in which information is recorded on and reproduced from the two information layers from one side, by using a laser beam that has been transmitted through the information layer on the laser beam incident side (hereinafter referred to as a first information layer), recording and reproduction of the information layer on the side opposite to the laser beam incident side (hereinafter referred to as a second information layer) is performed.

[0005]

[Patent document 1]

JP 2000-36130 A

[0006]

[Problem to be solved by the invention]

In order to perform recording and reproduction by using two recording layers, it is preferable that the first information layer has a transmittance as high as possible. As a means to solve this problem, the following technique has been studied: in the recording layer including at least a recording layer and a reflective layer in this order as viewed from the laser beam incident side, a transmittance adjusting layer made of a dielectric having a high refractive index is provided in contact with the side opposite to the laser beam incident side of the reflective layer in order to increase the transmittance. As a dielectric having a high refractive index, it is preferable to use, for example, titanium oxide ($TiO_2$), niobium oxide ($Nb_2O_5$) and materials containing these.

[0007]

The optical information recording medium including the transmittance adjusting layer made of the dielectric having a high refractive index is an information recording medium including: a first substrate and a second substrate; the first and the second information layers; and an optical separating layer. The information recording medium is manufactured in the following process in order to facilitate film-formation.

[0008]

(a) a process of forming the second information layer on the second substrate.

(b) a process of forming the optical separating layer on the second information layer.

(c) a process of forming the first information layer on the optical separating layer.

(d) a process of attaching the first substrate onto the first information layer.

In order words, in the conventional optical information recording medium including the transmittance adjusting layer, when forming the first information layer on the optical separating layer in the process (c), first, the transmittance adjusting layer made of a dielectric having a high refractive index is formed on the optical separating layer.

[0009]

However, when the inventors produced it with a single-wafer film-forming apparatus having a plurality of film-formation chambers, the following was made evident. When forming the transmittance adjusting layer made of a dielectric having a high refractive index in a first film-formation chamber, since the oxide dielectric having a high refractive index is very sensitive to an atmosphere for film formation, the film-forming rate tends to be varied by the influence of, for example, water contained in a base material. When a load lock chamber, which is the first chamber when a base material is introduced to a film-formation chamber, is kept in a vacuum for a long time, the variation in the film-forming rate can be suppressed. However, in view of productivity, this is not preferable because when a vacuum is kept for a long time, the film-forming cycle takes a long time.

[0010]

With the foregoing in mind, it is an object of the present invention to provide an optical information recording medium in which a transmittance adjusting layer made of a dielectric having a high refractive index can be formed stably, and a method for manufacturing the optical information recording medium.

[0011]

[Means for solving problem]

In order to achieve the above object, an optical information recording medium includes a first information layer and a second information layer that are separated from each other by an optical separating layer. The first information layer includes a low refractive

index layer that is in contact with a recording layer and the optical separating layer. With respect to a laser beam having a wavelength of $\lambda_o$ used to record on or reproduce from the optical information recording medium, when a refractive index of the low refractive index layer is taken as n1, and a refractive index of the optical separating layer is taken as n4, n1 and n4 satisfy $|n1-n4| \leq 0.5$. In this optical information recording medium, it is preferable that the first information layer includes at least the recording layer, a reflective layer, a transmittance adjusting layer, and the low refractive index layer in this order as viewed from a side into which the laser beam enters, and with respect to the laser beam, when a transmittance of the first information layer when the recording layer is in the crystalline state is taken as Tc1 (%), and a transmittance of the first information layer when the recording layer is in the amorphous state is taken as Ta1 (%), Tc1 and Ta1 satisfy $40 < Tc1$ and $40 < Ta1$, and with respect to the laser beam having a wavelength of $\lambda_o$, when a refractive index of the reflective layer is taken as n3, and an extinction coefficient thereof is taken as k3, a refractive index of the transmittance adjusting layer is taken as n2, an extinction coefficient thereof is taken as k2, one of the following relationships is satisfied: $1.0 \leq (n2-n3) \leq 3.0$ or $1.0 \leq (k3-k2) \leq 4.0$. Further, it is preferable that the low refractive index layer comprises at least one selected from the group consisting of $SiO_2$, $Al_2O_3$, $LaF_3$, $ZrSiO_4$, and $ZrO_2$. Further, it is preferable that a film thickness d1 of the low refractive index layer is in a range of 1 nm to 25 nm.

[0012]

In order to achieve the above object, a method for manufacturing an optical information recording medium of the present invention is a method for manufacturing an optical information recording medium including a first information layer and a second information layer that are separated by an optical separating layer, the method comprising:

(a) a step of forming the second information layer,

(b) a step of forming the optical separating layer on the second information layer, and

(c) a step of forming the first information layer on the optical separating layer,

and when forming the first information layer on the optical separating layer, the low refractive index layer, the transmittance adjusting layer,

and the reflective layer are formed in this order, and when a refractive index of the low refractive index layer is taken as n1, a refractive index of the transmittance adjusting layer is taken as n2, an extinction coefficient thereof is taken as k2, and a refractive index of the reflective layer is taken as n3, an extinction coefficient thereof is taken as k3, and a refractive index of the optical separating layer is taken as n4, n1 to n4 and k2 and k3 satisfy $1.0 \leq (n2-n3) \leq 3.0$ or $1.0 \leq (k3-k2) \leq 4.0$ and $|n1-n4| \leq 0.5$. Further, it is preferable that the low refractive index layer comprises at least one selected from the group consisting of $SiO_2$, $Al_2O_3$, $LaF_3$, $ZrSiO_4$, and $ZrO_2$. Further, it is preferable that a film thickness d1 of the low refractive index layer is in a range of 1 nm to 25 nm.

[0013] When forming the conventional transmittance adjusting layer made of the dielectric having a high refractive index in the first film-formation chamber, since the degree of moisture and gas contained in the substrate varies, the degree of reaction between the moisture and the gas and the dielectric material varies in each film formation, and thus the film-forming rates tend to vary. However, if a low refractive index layer is provided, at the time of forming the transmittance adjusting layer made of the dielectric having a high refractive index, it is not affected by the moisture contained in the substrate because the low refractive index layer is on the substrate. Thus, the variations in the film-forming rate can be prevented. Further, when a refractive index of the low refractive index layer is taken as n1, and a refractive index of the optical separating layer is taken as n4, by selecting the materials for the low refractive index layer and the optical separating layer so that n1 and n4 satisfy $|n1-n4| \leq 0.5$ and by setting the film thickness of the low refractive index layer in a range of 1 nm to 25 nm, it is possible to obtain an optical information recording medium in which the transmittance adjusting layer made of a dielectric having a high refractive index can be formed stably and a method for manufacturing the optical information recording medium.

[0014]

[Mode for carrying out the invention]

Hereinafter, embodiments of the present invention will be described with reference to the accompanying drawings. However, the present invention is not limited by these drawings.

[0015]

(Embodiment 1)

In Embodiment 1, one example of the optical information recording medium of the present invention will be described. The present invention relates to an optical information recording medium including n information layers that are separated from each other by an optical separating layer. Herein, n=2. That is, one example of an optical information recording medium including two information layers will be described, for example.

[0016]

FIG. 1 is a cross-sectional view in the radial direction showing a schematic multilayered structure of a two-layer optical information recording medium (optical disk) according to one embodiment of the present invention. This optical disk includes a plurality of recording layers. As shown in FIG. 1, a second substrate 5, a second information layer 4, an optical separating layer 3, a first information layer 2 and a first substrate 1 are laminated in sequence in the optical disk. Each of the two information layers 2, 4 that are provided via the optical separating layer 3 includes a recording film (not shown), and information is recorded in these two information layers 2, 4.

[0017]

FIG. 2 shows one example of a structure of the first information layer 2 and the second information layer 4. In an optical information recording medium 17, a second reflective layer 16, a second upper protective layer 15, a second recording layer 14, a second lower protective layer 13 are laminated in sequence on the second substrate 5, and via the optical separating layer 3, a low refractive index layer 12, a transmittance adjusting layer 11, a reflective layer 10, an upper protective layer 9, a recording layer 8, a lower interface layer 7, and a lower protective layer 6 are laminated in sequence and are protected by the first substrate 1. A laser beam 18 for performing recording and reproduction is made incident from the first substrate 1 side. As a method for forming the respective layers such as the second reflective layer 16, the second upper protective layer 15, the second recording layer 14, the second lower protective layer 13, the low refractive index layer 12, the transmittance adjusting layer 11, the reflective layer 10, the upper protective layer 9, the recording layer 8, the lower interface layer 7, and the lower protective layer 6, in general, electron beam evaporation,

sputtering, CVD, laser sputtering or the like can be used.

[0018]

Hereinafter, each component of the multilayered optical information recording medium will be described. For the materials of the optical separating layer 3 and the first substrate 1, resins such as light-curing resin (in particular, UV-curing resin), slow acting resin, or a laminate of a plurality of resins can be used. For the materials, it is preferable that the optical absorption with respect to the laser beam 18 used is small, and that the birefringence is optically small in a short wavelength region. For the first substrate 1, a transparent disk-shaped resins such as polycarbonate, amorphous polyolefin or PMMA, or glass can be used. In this case, the first substrate 1 can be formed by being attached to the lower protective layer 6 of the first information layer 2 with a resin such as a light-curing resin (in particular, UV-curing resin) or slow acting resin.

[0019]

The second substrate 5 is a disk-shaped substrate. In the second substrate 5, for example, resins such as polycarbonate, amorphous polyolefin or PMMA, or glass can be used.

[0020]

Guide grooves for guiding the laser beam may be formed, if necessary, on the surface of the second substrate 5 on the side of the second information layer 4. In the second substrate 5, it is preferable that the surface on the side opposite to the second information layer 4 side is smooth. For the material for the second substrate 5, polycarbonate is particularly preferable because of its excellent properties for transfer and mass production and its low cost. It is preferable that the thickness of the second substrate 5 is in the range from 400 μm to 1300 μm so that sufficient strength is provided and the thickness of the optical information recording medium 17 is about 1200 μm. In the case where the thickness of the first substrate 1 is about 600 μm (which allows satisfactory recording/reproduction at NA=0.6), it is preferable that it is in the range from 550 μm to 650 μm. In the case where the thickness of the first substrate 1 is about 100 μm (which allows satisfactory recording/reproduction at NA=0.85), it is preferable that it is in the range from 1150 μm to 1250 μm.

[0021]

In this case, even with irradiation of only the laser beam 18 from one side, information can be recorded/reproduced on/from the second information layer 4 with the laser beam 18 transmitted through the first information layer 2.

[0022]

It should be noted that either one of the first information layer 2 and the second information layer 4 may be a read-only (ROM (Read Only Memory)) information layer or a write-once (WO (Write-Once)) information layer that can be written only once.

[0023]

In the case of high density recording, the wavelength λ of the laser beam 18 is preferably 450 nm or less, in particular, because the diameter of a spot obtained when the laser beam 18 is focused is determined by the wavelength λ (as the wavelength λ is smaller, the light can be focused into a smaller spot). Moreover, if it is less than 350 nm, then the optical absorption with a resin used for the optical separating layer 10 or the first substrate 1 for example is increased. For these reasons, it is more preferable it is in the range from 350 nm to 450 nm.

[0024]

Hereinafter, the configuration of the first information layer 2 will be described in detail. The first information layer 2 includes the lower protective layer 6, the lower interface layer 7, the recording layer 8, the upper protective layer 9, the reflective layer 10, the transmittance adjusting layer 11, and the low refractive index layer 12 that are disposed in this order from the laser beam 18 incident side. Concerning the upper and the lower in the names of the interface layers and the protective layers, the lower indicates that those are on the laser beam 18 incident side than the recording layer and the upper indicates that those are on the opposite side to the laser beam 18 incident side with respect to the recording layer.

[0025]

The lower protective layer 6 is formed of a dielectric. The function of this lower protective layer 6 is to prevent oxidation, corrosion and deformation of the recording layer 8, to adjust the optical distance so as to increase the optical absorption efficiency of the recording layer 8, and to increase the signal amplitude by increasing the change in the

amount of reflected light before and after recording. For the lower protective layer 6, for example, oxides such as $SiO_x$ (x is 0.5 to 2.5), $Al_2O_3$, $TiO_2$, $Ta_2O_5$, $ZrO_2$, ZnO, and Te-O can be used. Furthermore, nitrides such as C-N, Si-N, Al-N, Ti-N, Ta-N, Zr-N, Ge-N, Cr-N, Ge-Si-N, or Ge-Cr-N can be used. Moreover, sulfides such as ZnS or carbides such as SiC also can be used. Moreover, it is also possible to use a mixture of the above materials. For example, ZnS-$SiO_2$, which is a mixture of ZnS and $SiO_2$, is particularly excellent as the material of the lower protective layer 6. ZnS-$SiO_2$ is an amorphous material, which has a high refractive index, fast film formation speed, and favorable mechanical properties and resistance against moisture.

[0026]

The thickness of the lower protective layer 6 can be determined precisely so as to satisfy the conditions that increase the change in the amount of the reflected light between when the recording layer 8 is in a crystalline phase and when it is in an amorphous phase and increase the transmittance of the first information layer 2 by calculation based on the matrix method (e.g., see the third chapter "Wave Optics", written by Hiroshi Kubota, Iwanami Shoten, 1971).

[0027]

The upper protective layer 9 has the function to adjust the optical distance to increase the optical absorption efficiency of the recording layer 8, and the function to increase the signal amplitude by increasing the change in the amount of reflected light before and after recording. The upper protective layer 9 can be made using an oxide such as $SiO_2$, $Al_2O_3$, $Bi_2O_3$, $Nb_2O_5$, $TiO_2$, $Ta_2O_5$, $ZrO_2$, and ZnO. It also can be made using a nitride, such as C-N, Si-N, Al-N, Ti-N, Ta-N, Zr-N, Ge-N, Cr-N, Ge-Si-N, Ge-Cr-N or Nb-N. Moreover, sulfides such as ZnS, carbides such as SiC and C also can be used. Moreover, it is also possible to use a mixture of the above materials. When a nitride is used for the upper protective layer 9, it serves to promote crystallization of the recording layer 8. In this case, materials containing Ge-N are formed easily by reactive sputtering, and have excellent mechanical properties and resistance against moisture. Of these, in particular, composite nitrides such as Ge-Si-N, or Ge-Cr-N are preferable. Furthermore, ZnS-$SiO_2$, which is a mixture of ZnS and $SiO_2$, is an amorphous material, and has a high refractive index, fast film formation speed, and favorable

mechanical properties and resistance against moisture, and therefore also is an excellent material for the upper protective layer 9.

[0028]

The film thickness d5 of the upper protective layer 9 is preferably in the range of $(1/64)\ \lambda\ /\ n5 \leq d5 \leq (1/4)\ \lambda\ /\ n5$, and more preferably $(1/64)\ \lambda\ /\ n5 \leq d5 \leq (1/8)\ \lambda\ /\ n5$, where n5 is the refractive index of the upper protective layer 9. It should be noted that for example, by selecting the wavelength $\lambda$ of the laser beam 18 and n3 so as to be, for example, 350 nm $\leq \lambda \leq$ 450 nm, $1.5 \leq n5 \leq 3.0$, the range can be preferably 2 nm $\leq d5 \leq$ 75 nm, more preferably 2 nm $\leq d5 \leq$ 40 nm. By choosing d5 from this range, it is possible to diffuse heat generated in the recording layer effectively to the side of the reflective layer 10.

[0029]

The transmittance adjusting layer 11 is made of a dielectric, and has the function to adjust the transmittance of the first information layer 2. With this transmittance adjusting layer 11, it is possible to increase both the transmittance Tc (%) of the first information layer 2 when the recording layer 8 is in the crystalline phase and the transmittance Ta (%) of the first information layer 2 when the recording layer 8 is in the amorphous phase. More specifically, in the first information layer 2 provided with the transmittance adjusting layer 11, the transmittance is increased by about 2% to 10%, compared with the case without the transmittance adjusting layer 11. Moreover, the transmittance adjusting layer 11 also has the effect to diffuse heat generated in the recording layer 8 effectively.

[0030]

It is preferable that the refractive index n2 and the extinction coefficient k2 of the transmittance adjusting layer 11 satisfy $2.0 \leq n2$ and $k2 \leq 0.1$, more preferably $2.0 \leq n2 \leq 3.0$ and $k2 \leq 0.05$, in order to increase the effect of enhancing the transmittances Tc and Ta of the first information layer 2.

[0031]

It is preferable that the film thickness d2 of the transmittance adjusting layer 11 is within the range of $(1/32)\lambda\ /n2 \leq d2 \leq (3/16)\lambda\ /n2$ or $(17/32)\lambda\ /n2 \leq d2 \leq (11/16)\lambda\ /n2$, and more preferably within the range of $(1/16)\lambda\ /n2 \leq d2 \leq (5/32)\lambda\ /n2$ or $(9/16)\lambda\ /n2 \leq d2 \leq (21/32)\lambda\ /n2$. It should be noted that by selecting the wavelength $\lambda$ of the laser beam 18 and n2

to be, for example, 350 nm $\leq \lambda \leq$ 450 nm and 2.0 $\leq$ n2 $\leq$ 3.0, the range can be preferably in 3 nm $\leq$ d2 $\leq$ 40 nm or 60 nm $\leq$ d2 $\leq$ 130 nm, and more preferably in the range of 7 nm $\leq$ d2 $\leq$ 30 nm or 65 nm $\leq$ d2 $\leq$ 120 nm. By choosing d2 from these ranges, both transmittances Tc and Ta of the first information layer 2 can be enhanced.

[0032]

The transmittance adjusting layer 11 can be made using, for example, oxides such as $TiO_2$, $ZrO_2$, ZnO, $Nb_2O_5$, $Ta_2O_5$, $SiO_2$, $Al_2O_3$, or $Bi_2O_3$. It also can be made using a nitride, such as Ti-N, Zr-N, Nb-N, Ta-N, Si-N, Ge-N, Cr-N, Al-N, Ge-Si-N, or Ge-Cr-N. It is also possible to use a sulfide, such as ZnS. Moreover, it is also possible to use a mixture of the above materials. Of these, in particular $TiO_2$ or a material including $TiO_2$ as the main component is used preferably. These materials have a high refractive index (n2=2.5 to 2.8) and a low extinction coefficient (k2=0.0 to 0.05), so that the effect of enhancing the transmittance of the first information layer 2 is large.

[0033]

The low refractive index layer 12 is made of a dielectric, and has the function to prevent moisture adsorbed to a base material when forming the transmittance adjusting layer 11. When forming the transmittance adjusting layer 11 made of a dielectric having a high refractive index by sputtering, it is very sensitive to an atmosphere for film formation. Therefore, when the low refractive index layer 12 is not provided, the film-forming rate tends to be varied by the influence of moisture or the like contained in the optical separating layer.

[0034]

Since the low refractive index layer 12 does not have to have an optical function, it is preferable that the difference between the refractive index n1 of the low refractive index layer 12 and the refractive index of the optical separating layer 3 is small, and it is preferable to satisfy $|n1-n4| \leq 0.5$, and it is further preferable to satisfy $|n1-n4| \leq 0.3$.

[0035]

In a single-wafer film-forming apparatus, the overall film-forming throughput is determined by the rate that is limited by the rate in a chamber with the longest film-formation time. The film thickness d1 of the low refractive index layer 12 is preferably in the

range from 1 nm to 25 nm in order not to reduce the overall film-forming throughput, and more preferably in the range from 5 nm to 15 nm. By choosing d1 in the range above, the low refractive index layer 12 that effectively prevents oxygen from the base material from affecting the atmosphere in the film-formation chamber when forming the transmittance adjusting layer 11 without limiting the film-forming throughput by the rate for the low refractive index layer 12 can be provided.

[0036]

The low refractive index layer 12 can be made using, for example, $SiO_2$, $Al_2O_3$, $LaF_3$, $ZrSiO_4$, or $ZrO_2$. Moreover, it is also possible to use a mixture of the above materials. Of these, in particular $SiO_2$ or a material including $SiO_2$ is used preferably. The refractive indexes of these materials ($n1=1.4$ to $1.6$) have no large difference from the refractive index of the optical separating layer 3, and they are more stable materials, and therefore are suitable as the low refractive index layer 12.

[0037]

The function of the lower interface layer 7 is to prevent the migration of substances between the lower protective layer 7 and the recording layer 8 due to repeated recording. The lower interface layer 7 can be made using nitrides such as C-N, Ti-N, Zr-N, Nb-N, Ta-N, Si-N, Ge-N, Cr-N, Al-N, Ge-Si-N, or Ge-Cr-N, oxides such as $Cr_2O_3$, or oxynitride containing these systems. Moreover, it can be made using C. Of these, materials containing Ge-N can be formed easily by reactive sputtering and become an interface layer having excellent mechanical properties and resistance against moisture. Of these, in particular, composite nitrides such as Ge-Si-N, or Ge-Cr-N are preferable. When the interface layer is thick, the reflectance or the absorption of the first information layer 2 is changed significantly so as to affect the recording/erasing performance. Therefore, it is preferable that the film thickness of the interface layer is in the range from 1 nm to 10nm, more preferably in the range from 2 nm to 5 nm.

[0038]

An upper interface layer may be provided at the interface between the recording layer 8 and the upper protective layer 9. In this case, the upper interface layer can be made using the materials

described with respect to the lower interface layer 7. It is preferable that the film thickness thereof is in the range from 1 nm to 10 nm (more preferably in the range from 2 nm to 5 nm) for the same reason as with the lower interface layer 7.

[0039]

Interface layers may be arranged between the upper protective layer 9 and the reflective layer 10 and between the reflective layer 10 and the transmittance adjusting layer 11. These interface layers have the function to prevent migration of substances between the upper protective layer 9 and the reflective layer 10 and between the reflective layer 10 and the transmittance adjusting layer 11 under high temperature and high humidity and in recording. In this case, the interface layers can be made using the materials described with respect to the lower interface layer 7. It is preferable that the film thickness thereof is in the range from 1 nm to 10 nm (more preferably in the range from 2 nm to 5 nm) for the same reason as with the lower interface layer 7.

[0040]

In the optical information recording medium 17 of the present invention, it is sufficient that the recording layer contains a substance that changes its structure between the crystalline state and the amorphous state, and it is a phase change material composed of, for example, Te, In or Se as the main component. Examples of the main component of well-known phase change materials include Te-Sb-Ge, Te-Ge, Te-Ge-Sn, Te-Ge-Sn-Au, Sb-Se, Sb-Te, Sb-Se-Te, In-Te, In-Se, In-Se-Tl, In-Sb, In-Sb-Se, and In-Se-Te. Of these, it was proved by investigating with experiments for materials that have favorable properties of repeated recording and erasure that compositions of these materials including three elements Ge, Sb, and Te as the main components are preferable. When the ratio of the atomic weight of these elements is expressed by $Ge_xSb_yTe_z$, the composition where $0.1 \leq x \leq 0.6$, $y \leq 0.5$, $0.4 \leq z \leq 0.65$ (where $x+y+z=1$) is particularly preferable.

[0041]

In the optical information recording medium 17 of the present invention, it is necessary to make the film thickness of the recording layer 8 as small as possible to increase the transmittance of the first information layer 2 in order that the amount of laser light necessary for

recording/reproduction reaches the information layer on the side opposite to the first information layer 2 as viewed from the laser beam 18 incident side. It is preferable that the film thickness of the recording layer 8 is in the range of 3 nm to 9 nm, and even more preferably in the range of 4 nm to 8 nm.

[0042]

The reflective layer 10 has the optical function to increase the amount of light that is absorbed by the recording layer 8. The reflective layer 10 also has the thermal function to quickly diffuse heat that is generated in the recording layer 8 to allow easier amorphization of the recording layer 8. Furthermore, the reflective layer 10 also has the function to protect the multi-layer film from the environment in which it is used.

[0043]

As the material of the reflective layer 10, it is possible to use a single metal with a high thermal conductivity, such as Ag, Au, Cu and Al. Moreover, an alloy including one or a plurality of these metal elements as the main component and to which one or a plurality of other elements are added in order to, for example, improve resistance against moisture or adjust thermal conductivity can be used. More specifically, alloys such as Al-Cr, Al-Ti, Au-Pd, Au-Cr, Ag-Pd, Ag-Pd-Cu, Ag-Pd-Ti, Ag-Ru-Au or Cu-Si can be used. In particular Ag alloys have a high thermal conductivity and a high transmittance of light, so that they are preferable as the material for the reflective layer 10.

[0044]

It is preferable that the refractive index n3 and the extinction coefficient k3 of the reflective layer 10 satisfy $n3 \leq 2.0$, and $1.0 \leq k3$, and more preferably $0.1 \leq n3 \leq 1.0$, and $1.5 \leq k3 \leq 4.0$ in order further to increase the transmittance of the first information layer 2.

[0045]

In order to make the transmittance Tc and the Ta of the first information layer 2 as high as possible, it is preferable that the film thickness of the reflective layer 10 is in the range from 3 nm to 15 nm, more preferably 8 nm to 12 nm. When the film thickness of the reflective layer 10 is smaller than 3 nm, the thermal diffusion function becomes insufficient and the reflectance of the first information layer 2 drops by 2 to 3 %. Further, when the reflective layer 10 is thicker than

15 nm, the transmittance of the first information layer 2 becomes insufficient.

[0046]

It is preferable that the refractive index n2 and the extinction coefficient k2 of the transmittance adjusting layer 11 and the refractive index n3 and the extinction coefficient k3 of the reflective layer 10 satisfy $1.0 \leq (n2-n3) \leq 3.0$ or $1.0 \leq (k2-k1) \leq 4.0$, more preferably $2.0 \leq (n2-n3) \leq 3.0$ or $1.5 \leq (k2-k1) \leq 3.0$. When these relationships are satisfied, light is confined in the transmittance adjusting layer 11 having a larger refractive index and a smaller extinction coefficient than those of the reflective layer 10, and the interference effect of light becomes large, so that the transmittance of the first information layer 2 can be increased. For example, when $TiO_2$ is used as the transmittance adjusting layer 11 and an Ag alloy is used as the reflective layer 10, n2=2.7, k2=0.0, n3=0.2, and k3=2.0 at a wavelength of 405 nm, and $(n2-n3) = 2.5$ and $(k3-k2) = 2.0$. Thus, it satisfies the above relationship.

[0047]

It is preferable that the refractive index n2 and the extinction coefficient k2 of the transmittance adjusting layer 11 and the refractive index n3 and the extinction coefficient k3 of the reflective layer 10 satisfy $1.0 \leq (n2-n3) \leq 3.0$ or $1.0 \leq (k3-k2) \leq 4.0$, more preferably $2.0 \leq (n2-n3) \leq 3.0$ or $1.5 \leq (k3-k2) \leq 3.0$. When these relationships are satisfied, light is confined in the transmittance adjusting layer 11 having a larger refractive index and a smaller extinction coefficient than those of the reflective layer 10, and the interference effect of light becomes large, so that the transmittance of the first information layer 2 can be increased. For example, when $TiO_2$ is used as the transmittance adjusting layer 11 and an Ag alloy is used as the reflective layer 10, n2=2.7, k2=0.0, n3=0.2, and k3=2.0 at a wavelength of 405 nm, and $(n2-n3) = 2.5$ and $(k3-k2) = 2.0$. Thus, it satisfies the above relationship.

[0048]

The optical separating layer 3 is provided for discriminating the focus position of the first information layer 2 of the optical information recording medium 17. It is necessary that the thickness of the optical separating layer 3 is equal to at least a focal depth $\Delta Z$ that is determined

by the numerical aperture NA of the objective lens and the wavelength $\lambda$ of the laser beam 18. When it is assumed that the reference intensity at the focal point is 80% of that in the case of no aberration, $\Delta Z$ can be approximated to $\Delta Z = \lambda /\{2(NA)^2\}$. When $\lambda$ = 400 nm and NA = 0.6, $\Delta Z$ = 0.556 μm, and the focal depth is within ± 0.6 μm. Therefore, in this case, it is necessary that the thickness of the optical separating layer 3 is 1.2 μm or more. It is preferable that the distance to the first information layer 2 is in the range in which the laser beam 18 can be focused using an objective lens. Therefore, it is preferable that the total of the thickness of the optical separating layer 3 is within a tolerance (e.g., 50 μm or less) that can be allowed by the objective lens.

[0049]

A guide groove for guiding the laser beam 18 may be formed on the surface of the optical separating layer 3 on the incident side of the laser beam, if necessary.

[0050]

In order for the amount of laser light necessary for recording/reproduction to reach the information layer on the side opposite to the first information layer 2 as viewed from the laser beam 18 incident side, it is preferable that the transmittances Tc and Ta of the first information layer 2 satisfy $40 < Tc1$, and $40 < Ta1$, and more preferably $43 < Tc1$ and $43 < Ta1$.

[0051]

It is preferable that the transmittances Tc and Ta of the first information layer 2 satisfy $-5 \leq (Tc1-Ta1) \leq 5$, and more preferably $-3 \leq (Tc1-Ta1) \leq 3$. When Tc1 and Ta1 satisfy these conditions, an effect of a change of the transmittance due to the state of the recording layer 8 of the first information layer 2 is small during recording/reproduction of the second information layer 4, and good recording/reproduction characteristics can be obtained.

[0052]

It is preferable that the reflectances Rc1 and Ra1 of the first information layer 2 satisfy $Ra1 < Rc1$. By doing this, the reflectance is high in an initial state in which information is not recorded, so that a recording/reproducing operation can be performed stably. Furthermore, it is preferable that Rc1 and Ra1 satisfy $0.1 \leq Ra1 \leq 5$ or $4 \leq Rc1 \leq 15$, more preferably, $0.5 \leq Ra1 \leq 3$ or $4 \leq Rc1 \leq 10$ so that a difference in the

reflectance (Rc1 - Ra1) can be large so that good recording/reproduction characteristics can be obtained.

[0053]

Hereinafter, the structure of the second information layer 4 will be described in detail. The second information layer 4 is formed of a second lower protective layer 13, a second recording layer 14, a second upper protective layer 15 and a second reflective layer 16 that are arranged in this order from the incident side of the laser beam 18. In the second information layer 4, information is recorded/reproduced by the laser beam 18 that has passed through the first substrate 1, the first information layer 2 and the optical separating layer 3.

[0054]

The second lower protective layer 13 is formed of a dielectric as the lower protective layer 6. The second lower protective layer 13 has the function to prevent oxidation, corrosion and deformation of the second recording layer 14, to adjust the optical distance in order to increase the optical absorption efficiency of the second recording layer 14, and to increase the signal amplitude by increasing the change in the amount of reflected light before and after recording. The second lower protective layer 13 can be made using, for example, oxides such as $SiO_x$ (where x is 0.5 to 2.5), $Al_2O_3$, $TiO_2$, $Ta_2O_5$, $ZrO_2$, ZnO, and Te-O can be used. It also can be made using a nitride, such as C-N, Si-N, Al-N, Ti-N, Ta-N, Zr-N, Ge-N, Cr-N, Ge-Si-N, or Ge-Cr-N. Moreover, sulfides such as ZnS or carbides such as SiC also can be used. Moreover, it is also possible to use a mixture of the above materials. As in the case of the lower protective layer 6, ZnS-$SiO_2$ is particularly excellent as the material of the second lower protective layer 13.

[0055]

The film thickness of the second lower protective layer 13 can be determined precisely so as to satisfy the conditions that increase the change in the amount of the reflected light between when the second recording layer 14 is in a crystalline phase and when it is in an amorphous phase and increase the transmittance of the first information layer 2 by calculation based on the matrix method as in the case of the lower protective layer 6.

[0056]

The second upper protective layer 15 has the function to adjust

the optical distance in order to increase the optical absorption efficiency of the second recording layer 14, and the function to increase the carrier level by increasing the change in the amount of reflected light before and after recording, as in the case of the upper protective layer 9. The second upper protective layer 15 can be made using an oxide such as $SiO_2$, $Al_2O_3$, $Bi_2O_3$, $Nb_2O_5$, $TiO_2$, $Ta_2O_5$, $ZrO_2$, and ZnO, as in the case of the upper protective layer 9. It also can be made using a nitride, such as C-N, Si-N, Al-N, Ti-N, Ta-N, Zr-N, Ge-N, Cr-N, Ge-Si-N, Ge-Cr-N or Nb-N. Moreover, sulfides such as ZnS, carbides such as SiC and C also can be used. Moreover, it is also possible to use a mixture of the above materials. When a nitride is used for the second upper protective layer 15, the second upper protective layer 15 serves to promote crystallization of the second recording layer 15, as in the case of the upper protective layer 9. In this case, materials containing Ge-N are preferable because they are formed easily by reactive sputtering, and have excellent mechanical properties and resistance against moisture. Of these, in particular, composite nitrides such as Ge-Si-N or Ge-Cr-N are preferable. Furthermore, ZnS-$SiO_2$ also is an excellent material for the second upper protective layer 15 as in the case of the upper protective layer 9.

[0057]

An interface layer may be provided at the interface between the second recording layer 14 and the second upper protective layer 15 or the second recording layer 14 and the second upper protective layer 13. In this case, for the interface layer, the materials described with reference to the lower interface layer 7 can be used. For the same reason as with the lower interface layer 7, it is preferable that the film thickness is in the range from 1 nm to 10 nm, (more preferably 2 nm to 5 nm).

[0058]

The material of the second recording layer 14 of the present invention is made of a material that changes the phase reversibly between the crystal phase and the amorphous phase by irradiation of the laser beam 18, as in the case of the recording layer 8. The second recording layer 14 is made of a phase change material including, for example, Te, In or Se as the main component, as in the case of the recording layer 8. Examples of the main component of well-known phase change materials include Te-Sb-Ge, Te-Ge, Te-Ge-Sn, Te-Ge-Sn-Au, Sb-Se, Sb-Te, Sb-Se-Te, In-Te, In-Se, In-Se-Tl, In-Sb, In-Sb-Se, and

In-Se-Te. Of these, it was proved by investigating with experiments for materials that have favorable repeated rewriting properties of recording and erasure and the compositions of these materials that materials including three elements Ge, Sb, and Te as the main components are preferable. Furthermore, when the ratio of the atomic weight of these elements is expressed by $Ge_xSb_yTe_z$, the composition where $0.1 \leq x \leq 0.6$, $y \leq 0.5$, $0.4 \leq z \leq 0.65$, (where $x+y+z=1$) is particularly preferable.

[0059]

In order to increase the recording sensitivity of the second information layer 4, it is preferable that the film thickness of the second recording layer 14 is in the range of 6 nm to 20 nm. Even in this range, when the second recording layer 14 is thick, heat is diffused in the in-plane direction so that thermal influence on an adjacent region becomes large. When second the recording layer 14 is thin, the reflectance of the second information layer 4 becomes small. Therefore, the film thickness of the second recording layer 14 is more preferably in the range of 9 nm to 15 nm.

[0060]

The second reflective layer 16 has the optical function to increase the amount of light that is absorbed by the second recording layer 14, as in the case of the reflective layer 10. Furthermore, as in the case of the reflective layer 10, the second reflective layer 16 also has the thermal function to diffuse quickly heat that is generated in the second recording layer 14, and to allow easier amorphization of the second recording layer 14. Furthermore, the second reflective layer 16 also has the function to protect the multi-layer film from the environment in which it is used, as in the case of the reflective layer 10.

[0061]

As the material of the second reflective layer 16, it is possible to use a single metal with a high thermal conductivity, such as Ag, Au, Cu or Al, as in the case of the reflective layer 10. More specifically, alloys such as Al-Cr, Al-Ti, Au-Pd, Au-Cr, Ag-Pd, Ag-Pd-Cu, Ag-Pd-Ti, Ag-Ru-Au or Cu-Si can be used. In particular, Ag alloys have a high thermal conductivity and a high transmittance of light, so that they are preferable as the material for the second reflective layer 16. The second information layer 4 does not need a high transmittance, so that it is preferable that the film thickness of the second reflective layer 16 is 30

nm or more, which provides a sufficient thermal diffusion function. Even in this range, when the second reflective layer 16 is thicker than 200 nm, the thermal diffusion function becomes too large, and the recording sensitivity of the second information layer 4 is decreased. Therefore, the film thickness of the second reflective layer 16 is preferably in the range from 30 nm to 200 nm.

[0062]

A metal layer may be provided at the interface between the second upper protective layer 15 and the second reflective layer 16. In this case, the material described with reference to the second reflective layer 16 can be used for the metal material. The film thickness is preferably in the range from 3 nm to 100 nm (more preferably 10 nm to 50 nm).

[0063]

The optical information recording medium 17 according to Embodiment 1 can be manufactured by a method described in Embodiment 2.

[0064]

(Embodiment 2)

In Embodiment 2, a method for manufacturing the optical information recording medium 17 of the present invention will be described. First, a second information layer 4 is formed. More specifically, first, a second substrate 5 (thickness is, for example, 1100 μm) is prepared, and is disposed in a film-formation apparatus.

[0065]

Then, a second reflective layer 16 is formed on the second substrate 5. The second reflective layer 16 can be formed by sputtering using a base material constituting the second reflective layer 16 in an Ar gas atmosphere or an atmosphere of a mixed gas of Ar gas and a reactive gas (at least one gas selected from oxygen gas and nitrogen gas). In this case, when a guide groove for guiding the laser beam 18 to the second substrate 5 is formed, the second reflective layer 16 is formed on the side in which the guide groove is formed.

[0066]

Then, an second upper protective layer 15 is formed on the second reflective layer 16. The second upper protective layer 15 can be formed by sputtering using a base material constituting the second upper

protective layer 15 in an Ar gas atmosphere or an atmosphere of a mixed gas of Ar gas and a reactive gas.

[0067]

Then, a second recording layer 14 is formed on the second upper protective layer 15. Furthermore, an interface layer is formed between the second upper protective layer 15 and the second recording layer 14, if necessary.

[0068]

The second recording layer 14 can be formed by sputtering using a base material made of a material including Te, In, Se or the like as the main component in accordance with its composition, using one power.

[0069]

For the atmosphere gas (sputtering gas) for sputtering, Ar gas, Kr gas, a mixed gas of Ar gas and Kr gas, a mixed gas of Ar gas and a reactive gas (at least one gas selected from oxygen gas and nitrogen gas), or a mixed gas of Kr gas and a reactive gas can be used.

[0070]

As described in Embodiment 1, the film thickness of the second recording layer 14 is preferably in the range from 1 nm to 9 nm, more preferably in the range from 4 nm to 8 nm. The film-forming rate of the second recording layer 14 can be controlled by power introduced from a power source. If the film-forming rate is reduced too much, it takes a long time to form a film, and in addition to that, gas in the atmosphere can enter the recording layer more than necessary. If the film-forming rate is increased too much, the film-formation time can be short, but it becomes difficult to control the film thickness precisely. Therefore, the film-forming rate of the second recording layer 14 is preferable in the range from 0.1 nm / sec to 6 nm / sec.

[0071]

Then, a second lower protective layer 13 is formed on the second recording layer 14. The second lower protective layer 13 can be formed by sputtering using a base material constituting the second lower protective layer 13 in an Ar gas atmosphere or an atmosphere of a mixed gas of Ar gas and a reactive gas. Furthermore, an interface layer is formed between the second recording layer 14 and the second lower protective layer 13, if necessary.

[0072]

Thus, the second information layer 4 is formed. Then, an optical separating layer 3 is formed on the second lower protective layer 13 of the second information layer 4. The optical separating layer 3 can be made by applying and spin-coating a light-curing resin (in particular a UV-curing resin) or a slow-acting resin on the second lower protective layer 13, and then curing the resin. When the optical separating layer 3 is provided with a guide groove of the laser beam 18, the guide groove can be formed by attaching a substrate (mold) in which the groove is formed to a resin that is not cured yet, curing the resin, and then detaching the substrate (mold) therefrom.

[0073]

If necessary, it is also possible to perform an initialization step of crystallizing the entire second recording layer 14, after the second lower protective layer 13 has been formed or after the optical separating layer 3 has been formed. The crystallization of the second recording layer 14 can be performed by irradiating a laser beam 18.

[0074]

Subsequently, the first information layer 2 is formed on the optical separation layer 3. More specifically, first, the second substrate 5 in which and the optical separating layer 3 is formed after the second information layer 4 has been laminated is disposed in a film-forming apparatus, and a low refractive index layer 12 is formed on the optical separating layer 3. The low refractive index layer 12 can be formed by sputtering using a base material constituting the low refractive index layer 12 in an Ar gas atmosphere or an atmosphere of a mixed gas of Ar gas and a reactive gas.

[0075]

Subsequently, the transmittance adjusting layer 11 is formed on the low refractive index layer 12. The transmittance adjusting layer 11 can be formed by sputtering using a base material constituting the transmittance adjusting layer 11 in an Ar gas atmosphere or an atmosphere of a mixed gas of Ar gas and a reactive gas.

[0076]

Subsequently, the reflective layer 10 is formed on the transmittance adjusting layer 11. The reflective layer 10 can be formed by sputtering using a base material constituting the reflective layer 10 in an Ar gas atmosphere or an atmosphere of a mixed gas of Ar gas and a

reactive gas.

[0077]

Subsequently, the upper protective layer 9 is formed on the reflective layer 10. The upper protective layer 9 can be formed by sputtering using a base material constituting the upper protective layer 9 in an Ar gas atmosphere or an atmosphere of a mixed gas of Ar gas and a reactive gas.

[0078]

Subsequently, the recording layer 8 is formed on the upper protective layer 9. The recording layer 8 can be formed by sputtering using a sputtering a base material including Te, In, Se or the like as the main component in accordance with its composition, using one power source.

[0079]

For the sputtering gas atmosphere (sputtering gas), it is possible to use Ar gas, Kr gas, a mixed gas of Ar gas and reactive gas, or a mixed gas of Kr gas and reactive gas (at least one gas selected from oxygen gas and nitrogen gas).

[0080]

It is preferable that the film thickness of the recording layer 8 is in the range of 1 nm to 9 nm, and even more preferably in the range of 4 nm to 8 nm, as described in Embodiment 1. The film-forming rate of the recording layer 8 can be controlled by the power introduced from a power source. When the film-forming rate is reduced too much, it takes a long time to form a film, and in addition to that, gas in the atmosphere enters the recording layer 8 more than necessary. When the film-forming rate is increased too much, the film forming time can be reduced, but it becomes difficult to control the film thickness precisely. Therefore, it is preferable that the film-forming rate of the recording layer 8 is in the range from 0.1 nm/sec to 6 nm/sec. .

[0081]

Subsequently, a low interface layer 7 is formed on the recording layer 8, if necessary. The lower interface layer 7 can be formed by sputtering using a base material constituting the lower interface layer 7 in an Ar gas atmosphere or an atmosphere of a mixed gas of Ar gas and a reactive gas.

[0082]

Subsequently, a lower protective layer 6 is formed on the recording layer 8 or the lower interface layer 7, if necessary. The lower protective layer 6 can be formed in the same manner with the upper protective layer 9. The composition of the base material used when forming these protective layers can be selected in accordance with the composition of the protective layer and the sputtering gas. In other words, these protective layers may be formed using base materials having the same composition, or may be formed using base materials having different compositions.

[0083]

Interface layers may be arranged between the upper protective layer 9 and the reflective layer 10 and between the reflective layer 10 and the transmittance adjusting layer 11. The interface layers in this case can be formed in the same manner with the lower interface layer 7 (the same applies to the following interface layers).

[0084]

Finally, the first substrate 1 is formed on the lower protective layer 6. The first substrate 1 can be made by applying and spin-coating a light-curing resin (in particular a UV-curing resin) or a slow-acting resin on the lower protective layer 6, and then curing the resin. Furthermore, for the first substrate 1, transparent disk-shaped substrates made of resins such as polycarbonate, amorphous polyolefin or PMMA, or glass can be used. In this case, a light-curing resin (in particular a UV-curing resin) or a slow-acting resin is applied on the lower protective layer 6, the substrate is adhered to the lower protective layer 6 and spin-coating is performed, and then the resin is cured to form the first substrate.

[0085]

It should be noted that, if necessary, it is also possible to perform an initialization step of crystallizing the entire recording layer 8, after the lower protective layer 6 has been formed or after the first substrate 1 has been formed. The crystallization of the recording layer 8 can be performed by irradiating a laser beam 18. Thus, the optical information recording medium 17 can be produced as described above.

[0086]

(Embodiment 3)

In Embodiment 3, a method for recording/reproducing the optical

information recording medium 17 of the present invention as explained in Embodiment 1 will be described. A recording/reproducing apparatus used for the recording/reproducing method of the present invention will be described. FIG. 3 schematically shows the configuration of a portion of a recording/reproducing apparatus 23 used for a recording/reproducing method of this embodiment. With reference to FIG. 3, the recording/reproducing apparatus 23 includes a spindle motor 22 for rotating the optical information recording medium 17, an optical head 21 provided with a semiconductor laser 20, and an objective lens 19 for focusing the laser beam 18 emitted from the semiconductor laser 20.

[0087]

The optical information recording medium 17 is an optical information recording medium described in Embodiment 1 and includes a plurality of information layers (for example, the first information layer 2 and the second information layer 4). The first information layer 2 includes the recording layer 8, and the second information layer 4 includes the second recording layer 14. The objective lens 19 focuses the laser beam 18 onto the information layers (the recording layer 8 in the case of the first information layer 2, and the second recording layer 14 in the case of the second information layer 4.).

[0088]

Information is recorded, erased and overwritten on the optical information recoding medium 17 (in particular, the first information layer 2 or the second information layer 4) by modulating the power of the laser beam 18 between the peak power (Pp (mW)) of a high power and the bias power (Pb (mW)) of a low power. By irradiating a laser beam 18 with the peak power, an amorphous phase is formed in a local portion of the recording layer 8 or the second recording layer 14, and this amorphous phase serves as a recording mark. Between recording marks, a laser beam 18 with the bias power is irradiated, and a crystalline phase (erased portion) is formed. It should be noted that if the laser beam 18 is irradiated with the peak power, then so-called multi-pulses are common, in which a pulse train is formed. The multi-pulses may be formed by modulating only with the power levels of the peak power and the bias power, or they may be formed by modulating with power levels in the range of 0 mW to the peak power.

[0089]

Moreover, information signals are reproduced by setting as the reproduction power (Pr (mW)) a power that is lower than the power level of the peak power and the bias power, which does not influence the optical state of the recording marks when irradiating the laser beam 18 with this power level, and with which a sufficient amount of reflected light for the reproduction of the recording marks from the optical information recording medium 17 can be attained. The signals from the optical information recording medium 17 obtained by irradiating a laser beam 18 with this reproduction power are read with a detector, thus reproducing the information signal.

[0090]

The numerical aperture (NA) of the objective lens 19 is preferably within the range of 0.5 and 1.1 (more preferably within the range of 0.6 and 1.0) in order to adjust such that the spot diameter of the laser beam is within the range of 0.4 μm and 0.7 μm. It is preferable that the wavelength of the laser beam 18 is not greater than 450 nm (more preferably in the range of 350 nm to 450 nm). It is preferable that the linear speed of the optical information recording medium 17 when recording information is in the range of 3 m/sec to 20 m/sec (more preferably in the range of 4 m/sec to 15 m/sec), because in this range crystallization due to the reproduction light tends not to occur and a sufficient erasure capability is attained.

[0091]

When recording information on the first information layer 2, the laser beam 18 is focused on the recording layer 8, and information is recorded on the recording layer 8 by the laser beam 18 that has passed through the first substrate 1. The reproduction is performed using the laser beam 18 that has been reflected by the recording layer 8 and passed through the first substrate 1. When recording information on the second information layer 4, the laser beam 18 is focused on the second recording layer 14, and information is recorded with the laser beam 18 that has passed through the first substrate 1, the first information layer 2 and the optical separating layer 3. The reproduction of information is performed using the laser beam 18 that has been reflected by the second recording layer 14 and passed through the optical separating layer 3, the first information layer 2 and the first information layer 2.

[0092]

It should be noted that if guide grooves for guiding the laser beam 18 are formed in the second substrate 5 and the optical separating layer 3, then the recording may be performed on the groove surface (grooves) that is closer to the incident side of the laser beam 18, or on the groove surface (lands) that is further away therefrom. Information may be recorded on both the grooves and the lands.

[0093]

The recording performance was evaluated by recording marks having a length of 2T using a (8-15) modulation scheme, and by measuring the carrier to noise ratio (CNR) of the amplitude using a spectrum analyzer. The erasure performance was evaluated as follows. Marks having a length of 2T were recorded using a (8-15) modulation scheme, and the amplitude was measured using a spectrum analyzer. Then, marks having a length of 9T were overwritten on the marks having a length of 2T, the amplitude of the 2T signal was measured again, and the damping factor of the 2T signal was calculated. Hereinafter, the damping factor of the 3T signal will be referred to as erasure capability.

[0094]

[Working Examples]

The following is a more detailed explanation of the present invention using working examples.

[0095]

(Working Example 1)

In Working Example, the first information layer 2 of the optical information recording medium 17 in FIG. 2 was produced, and the relationship between the refractive index n1 and the film thickness d1 of the low refractive index layer and the transmittance and reflectance of the first information layer 2 was investigated. More specifically, samples obtained by producing the first information layers 2 having different material and film thickness of the low refractive index layer 12, and forming the first substrate 1 were produced. Regarding the produced samples, the reflectance of the first information layer 2 was measured.

[0096]

The samples were produced in the following manner. First, a

polycarbonate substrate (diameter: 120 mm, thickness: 1100 μm, refractive index: 1.62) was prepared as a substrate. Then, on this polycarbonate substrate, the low refractive index layer 12 (thickness: -), a $TiO_2$ layer (thickness: 20 nm) as the transmittance adjusting layer 11, a Ag-Pd-Cu layer (thickness: 10 nm) as the reflective layer 10, a Zr-Si-Cr-O layer (thickness: 10 nm) as the upper protective layer 9, a GeSbTe layer (thickness: 6 nm) as the recording layer 8, a Zr-Si-Cr-O layer (thickness: 5 nm) as the lower interface layer 7, and a ZnS-$SiO_2$ layer (thickness: 40 nm, $SiO_2$: 20 mol%) as the lower protective layer 6 were laminated sequentially by sputtering. An $SiO_2$ layer, an $Al_2O_3$ layer, a $ZrO_2$ layer, and a ZnS-$SiO_2$ layer were used as the low refractive index layer 12. Finally, the first substrate 1 was formed by applying a UV-curing resin on the lower protective layer 6, performing spin-coating with a polycarbonate substrate (diameter:120 mm, thickness: 90 μm) adhered to the lower protective layer 6, and then irradiating UV rays to cure the resin. A plurality of samples for measuring the transmittance having different materials and thickness of the low refractive index layer 12 were produced in this manner.

[0097]

Regarding the thus obtained samples, first, the reflectance Ra1 (%) in the case where the recording layer 8 is in an amorphous phase was measured. Thereafter, an initialization process to crystallize the recording layer 8 was performed, and the reflectance Rc1 (%) in the case where the recording layer 8 is in a crystalline phase was measured. For measurement of the reflectance, the recording/reproducing apparatus 23 in FIG. 3 was used. More specifically, the reflectance was measured by rotating the samples with a spindle motor 22, irradiating and focusing the laser beam 18 with a wavelength of 405 nm on the recording layer 8 of the first information layer 2 and measuring the amount of the reflected light.

[0098]

Table 1 shows the results of the measurement of the reflectance of the first information layer 2. The refractive index n1 of the $SiO_2$ layer used as the low refractive index layer in a wavelength of 405 nm was 1.49, the refractive index n1 of the $Al_2O_3$ layer in a wavelength of 405 nm was 1.70, the refractive index n1 of the $ZrO_2$ layer in a wavelength of 405 nm was 2.12, and the refractive index n1 of the

$ZnS\text{-}SiO_2$ layer in a wavelength of 405 nm was 2.34. It should be noted that ○ indicates that the reflectance Rc1 in the specular portion of the substrate of the first information layer 2 when the recording layer 8 is in the crystalline phase is in the range $4 \le Rc1 \le 15$, and the reflectance Ra1 in the specular portion of the substrate of the first information layer 2 when the recording layer 8 is in the amorphous phase is in the range $0.1 \le Ra1 \le 5$, and × indicates that either one of them is outside that range.

[0099]

[TABLE 1]

| sample No. | material of low refractive index layer | $\lvert n1-n4 \rvert$ | d1(nm) | Rc1(%) | Ra1(%) | evaluation |
|---|---|---|---|---|---|---|
| 1-a | $SiO_2$ | 0.13 | 1 | 6.4 | 1.4 | ○ |
| 1-b | $SiO_2$ | 0.13 | 5 | 6.2 | 1.3 | ○ |
| 1-c | $SiO_2$ | 0.13 | 10 | 5.9 | 1.2 | ○ |
| 1-d | $SiO_2$ | 0.13 | 20 | 5.7 | 1.0 | ○ |
| 1-e | $SiO_2$ | 0.13 | 25 | 5.2 | 0.9 | ○ |
| 1-f | $SiO_2$ | 0.13 | 30 | 5.1 | 0.9 | ○ |
| 1-g | $Al_2O_3$ | 0.08 | 1 | 6.5 | 1.5 | ○ |
| 1-h | $Al_2O_3$ | 0.08 | 5 | 6.6 | 1.5 | ○ |
| 1-i | $Al_2O_3$ | 0.08 | 10 | 6.8 | 1.6 | ○ |
| 1-j | $Al_2O_3$ | 0.08 | 20 | 7.1 | 1.8 | ○ |
| 1-k | $Al_2O_3$ | 0.08 | 25 | 7.3 | 1.9 | ○ |
| 1-l | $Al_2O_3$ | 0.08 | 30 | 7.4 | 1.9 | ○ |
| 1-m | $ZrO_2$ | 0.50 | 1 | 6.7 | 1.6 | ○ |
| 1-n | $ZrO_2$ | 0.50 | 5 | 7.8 | 2.2 | ○ |
| 1-o | $ZrO_2$ | 0.50 | 10 | 9.3 | 3.0 | ○ |
| 1-p | $ZrO_2$ | 0.50 | 20 | 11.8 | 4.5 | ○ |
| 1-q | $ZrO_2$ | 0.50 | 25 | 12.6 | 4.9 | ○ |
| 1-r | $ZrO_2$ | 0.50 | 30 | 12.9 | 5.2 | × |
| 1-s | $ZnS\text{-}SiO_2$ | 0.72 | 1 | 6.8 | 1.6 | ○ |
| 1-t | $ZnS\text{-}SiO_2$ | 0.72 | 5 | 8.4 | 2.5 | ○ |
| 1-u | $ZnS\text{-}SiO_2$ | 0.72 | 10 | 10.5 | 3.8 | ○ |
| 1-v | $ZnS\text{-}SiO_2$ | 0.72 | 20 | 13.8 | 5.8 | × |
| 1-w | $ZnS\text{-}SiO_2$ | 0.72 | 25 | 14.6 | 6.3 | × |
| 1-x | $ZnS\text{-}SiO_2$ | 0.72 | 30 | 14.9 | 6.5 | × |

[0100]

These results show that the samples 1-a, 1-b, 1-c, 1-d, 1-e, and 1-f in which the material of the low refractive index layer 12 is made of $SiO_2$ and has a film thickness d1 of 1 nm to 30 nm have a reflectance satisfying $4 \le Rc1 \le 15$, and $0.5 \le Ra1 \le 5$.

[0101]

Furthermore, the samples 1-g, 1-h, 1-i, 1-j, 1-k, and 1-l in which the material of the low refractive index layer 12 is made of $Al_2O_3$ and has a film thickness d1 of 1 nm to 30 nm have a reflectance satisfying 4 ≤ Rc1 ≤ 15, and 0.5 ≤ Ra1 ≤ 5.

[0102]

Furthermore, the samples 1-m, 1-n, 1-o, 1-p, and 1-q in which the material of the low refractive index layer 12 is made of $ZrO_2$ and has a film thickness d1 of 1 nm to 25 nm have a reflectance satisfying 4 ≤ Rc1 ≤ 15, and 0.5 ≤ Ra1 ≤ 5. The reflectance of a sample 1-r having a film thickness d1 of 30 nm was larger than 5%, and thus the reflectance was insufficient.

[0103]

Furthermore, the samples 1-s, 1-t, and 1-u in which the material of the low refractive index layer 12 is made of $ZnS\text{-}SiO_2$ and has a film thickness d1 of 1 nm to 10 nm have a reflectance satisfying 4 ≤ Rc1 ≤ 15, and 0.5 ≤ Ra1 ≤ 5. The reflectance of samples 1-v, 1-w, and 1-x having a film thickness d1 of 20 to 30 nm was larger than 5%, and thus the reflectance was insufficient.

[0104]

As shown in Table 1, when a material having a large refractive index n1 is used for the low refractive index layer 12, Rc1 and Ra1 become large. The above results showed that in order for the range to be in 1 nm to 25 nm and for the reflectance index to satisfy 4 ≤ Rc1 ≤ 15, and 0.1 ≤ Ra1 ≤ 5, it is preferable that the refractive index n1 of the low refractive index layer 12 satisfies, when the refractive index of the optical separating layer 3 is n4, $|n1\text{-}n4| \leq 0.5$.

[0105]

(Working Example 2)

In Working Example 2, the film-forming rate of the material constituting the transmittance adjusting layer when the low refractive index layer was provided was compared with the film-forming rate of the material constituting the transmittance adjusting layer when the low refractive index layer is not provided.

[0106]

The film-forming rate was measured in the following manner. First, in the case of providing the low refractive index layer, samples were formed by preparing a substrate for rate measurement and

laminating $SiO_2$ (thickness: 10nm) as the low refractive index layer 12 and $TiO_2$ (thickness: 20 nm) as the transmittance adjusting layer 11 sequentially on the substrate by sputtering. Next, in the case of not providing the low refractive index layer, samples were formed by preparing a substrate for rate measurement and laminating $TiO_2$ (thickness: 20 nm) as the transmittance adjusting layer 11 on the substrate by sputtering. By measuring the film thickness of the samples of the both cases (five samples each), the stability of the film-forming rate of $TiO_2$ was examined.

[0107]

Table 2 shows the results of the measurement of the film thickness when the low refractive index layer is provided and not provided. ○ indicates that the film-forming rate is within ± 1% from 22.0Å/sec, and △ indicates that the film-forming rate is within ± 3%, and × indicates that the rate is ± 3% or more.

[0108]

[TABLE 2]

| sample No. | low refractive index layer | film-forming rate of $TiO_2$ (Å/sec) | evaluation |
|---|---|---|---|
| 2-a | present | 22.1 | ○ |
| 2-b | present | 21.6 | △ |
| 2-c | present | 22.2 | ○ |
| 2-d | present | 21.9 | ○ |
| 2-e | present | 22.5 | △ |
| 2-f | absent | 15.6 | × |
| 2-g | absent | 18.6 | × |
| 2-h | absent | 19.9 | × |
| 2-i | absent | 16.7 | × |
| 2-j | absent | 18.8 | × |

[0109]

The results confirmed the following. In the samples 2-a, 2-b, 2-c, 2-d, and 2-e that were provided with the low refractive index layer, the film-forming rate of $TiO_2$ was stable, and films can be formed with sufficiently high reproducibility. On the other, in the samples 2-f, 2-g, 2-h, 2-i, and 2-j that were not provided with the low refractive index layer, it was found out that the film forming was such that the film-forming rate of $TiO_2$ was unstable and had a large variation in film thickness. The same results were produced when the transmittance

adjusting layer was not $TiO_2$ and the low refractive index layer was not $SiO_2$, for example, when the transmittance adjusting layer was $Nb_2O_5$ and the low refractive index layer was $Al_2O_3$. The results above show that it is preferable to provide the low refractive index layer to stabilize the film-forming rate of the transmittance adjusting layer.

[0110]

[Effect of the Invention]

As described above, according to the present invention, a transmittance adjusting layer of a multilayer optical information recording medium can be formed stably. When forming the conventional transmittance adjusting layer made of the dielectric having a high refractive index in the first film-formation chamber, reactive sputtering occurs due to the effect of unstable moisture contained in the substrate, and thereby the film-forming rate tends to vary. However, if a low refractive index layer is provided, at the time of forming the transmittance adjusting layer made of the dielectric having a high refractive index, the layer is not affected by the moisture contained in the substrate because the low refractive index layer is on the substrate. Thus, the variations in film-forming rate can be prevented. Further, when a refractive index of the low refractive index layer is taken as n1, and a refractive index of the optical separating layer is taken as n4, by selecting the materials for the low refractive index layer and the optical separating layer so that n1 and n4 satisfy $|n1-n4| \leq 0.5$ and by setting the film thickness of the low refractive index layer in a range of 1 nm to 25 nm, it is possible to obtain an optical information recording medium in which the transmittance adjusting layer made of a dielectric having a high refractive index can be formed stably and a method for manufacturing the optical information recording medium.

[Brief description of the drawings]

[FIG. 1]

A cross-sectional view showing the two-layer optical disk according to Embodiment 1 of the present invention.

[FIG. 2]

A cross-sectional view showing the first and the second information layers more specifically.

[FIG. 3]

A diagram schematically showing the configuration of a portion of

a recording/reproducing apparatus used for recording/reproducing the optical information recording medium of the present invention.

[Description of reference numerals]

| | |
|---|---|
| 1 | First substrate |
| 2 | First information layer |
| 3 | Optical separating layer |
| 4 | Second information layer |
| 5 | Second substrate |
| 6 | Lower protective layer |
| 7 | Lower interface layer |
| 8 | Recording layer |
| 9 | Upper protective layer |
| 10 | Reflective layer |
| 11 | Transmittance adjusting layer |
| 12 | Low refractive index layer |
| 13 | Second lower protective layer |
| 14 | Second recording layer |
| 15 | Second upper protective layer |
| 16 | Second reflective layer |
| 17 | Optical information recording medium |
| 18 | Laser beam |
| 19 | Objective lens |
| 20 | Semiconductor laser |
| 21 | Optical head |
| 22 | Spindle motor |
| 23 | Recording/reproducing apparatus |

[DOCUMENT NAME] ABSTRACT

[Abstract]

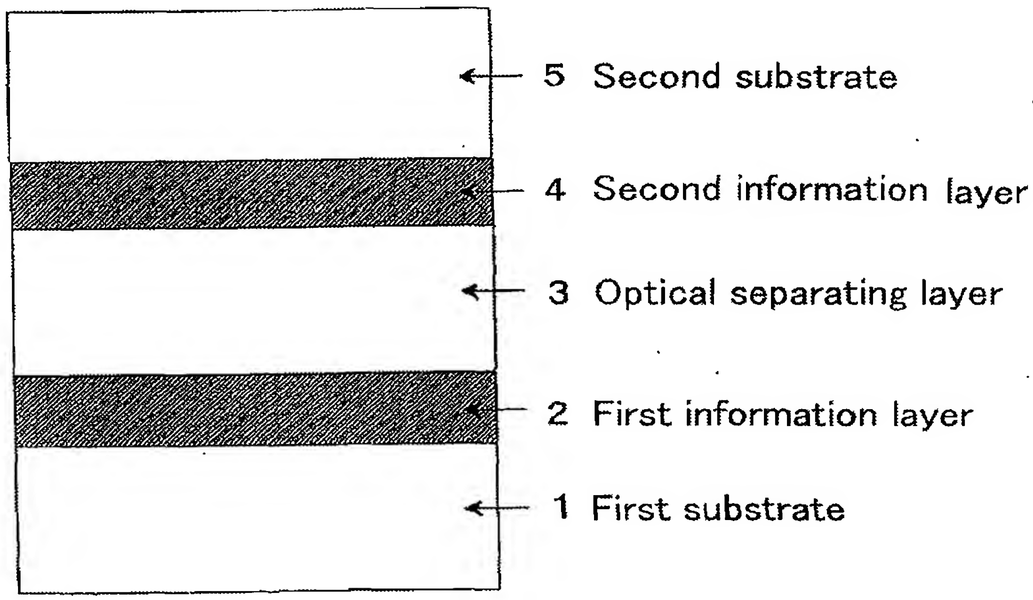
[Objects] In optical information recording media in which at least two information layers are formed, the present invention provides an optical information recording medium in which a transmittance adjusting layer made of a dielectric having a high refractive index can be formed stably and a method for manufacturing the optical information recording medium.

[Means] In an optical information recording medium that includes a first information layer and a second information layer that are separated from each other by an optical separating layer, the first information layer includes a low refractive index layer that is in contact with a recording layer and the optical separating layer, and with respect to a laser beam having a wavelength of $\lambda_o$ used to record on or reproduce from the optical information recording medium, when a refractive index of the low refractive index layer is taken as n1, and a refractive index of the first optical separating layer is taken as n4, n1 and n4 satisfy $|n1-n4| \leq 0.5$.

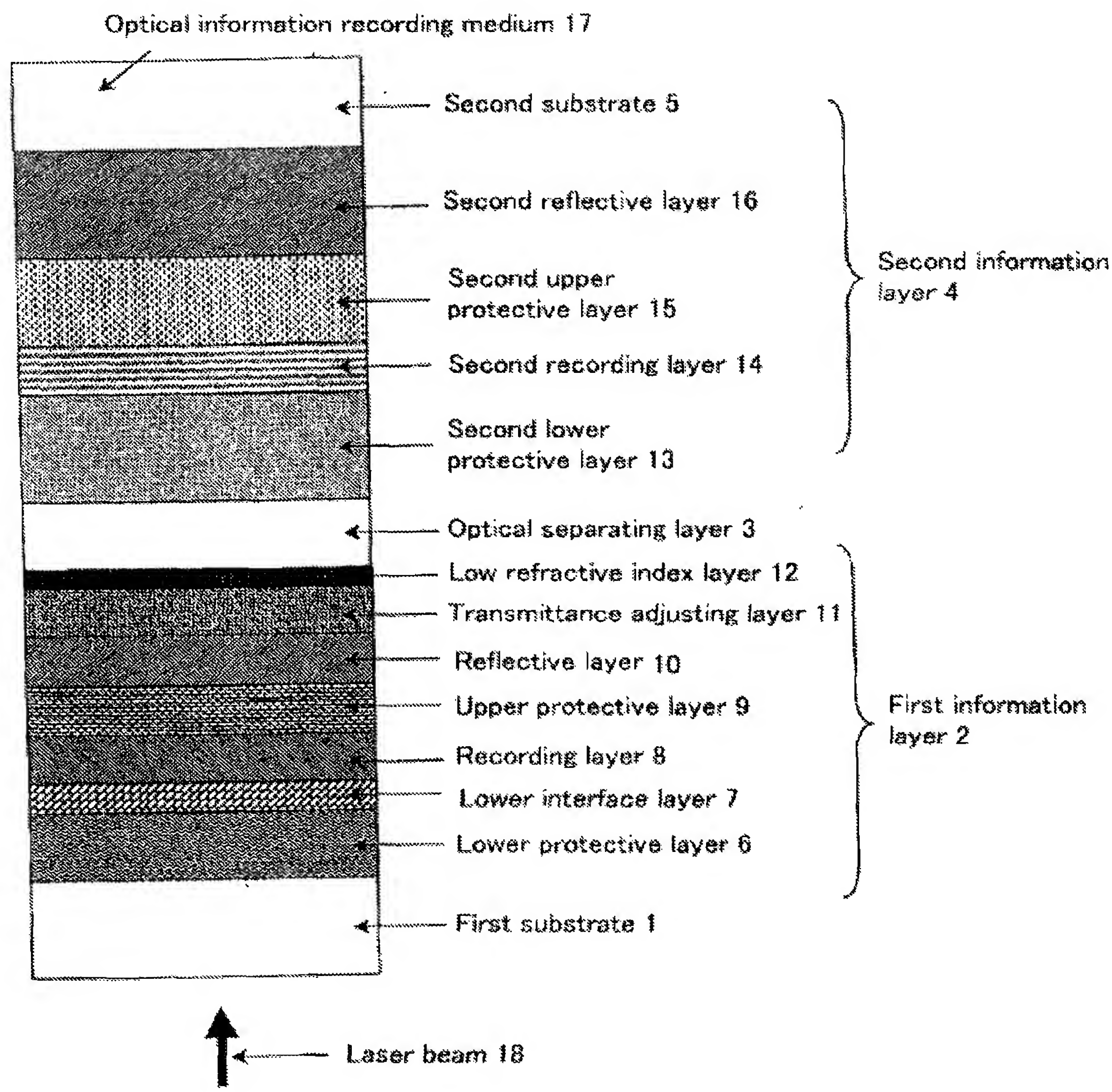
[Selected figure] FIG. 2

[DOCUMENT NAME] DRAWINGS

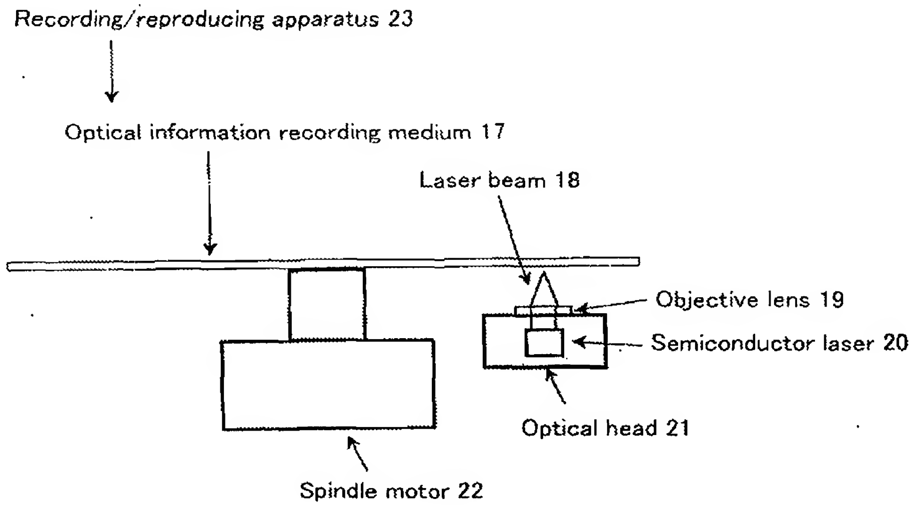
[FIG. 1]



[FIG. 2]


Optical information recording medium 17
Second substrate 5
Second reflective layer 16
Second upper protective layer 15
Second recording layer 14
Second lower protective layer 13
Second information layer 4
Optical separating layer 3
Low refractive index layer 12
Transmittance adjusting layer 11
Reflective layer 10
Upper protective layer 9
Recording layer 8
Lower interface layer 7
Lower protective layer 6
First information layer 2
First substrate 1
Laser beam 18

[FIG. 3]


Recording/reproducing apparatus 23
Optical information recording medium 17
Laser beam 18
Objective lens 19
Semiconductor laser 20
Optical head 21
Spindle motor 22